Fields are universal. In science, engineering, and mathematics we encounter flow fields, electric fields, magnetic fields, charge density fields, mass density fields, gravity fields, images (light intensity fields), and configuration space trajectory fields to name a few.

The essential qualitative aspects of any field-based phenomena are largely determined by the *topology* of the underlying fields—that is, by the locations, types, and interconnections of the *critical points* in those fields. Examples of critical points include maxima, minima, attractors, repellors, saddle points, foci, centers, and rarer (degenerate) forms.

In fluid dynamics, critical points indicate phenomena such as *flow separation points, attachment points,* and *stagnation points*. Similarly, in the charge density field of a molecule or crystal (using the quantum theory of atoms in molecules, or QTAIM), critical points indicate the presence of a nucleus, bond point, or reactive site. And in the cosmological mass density field, different types of critical points indicate the presence of galaxy clusters, filaments, and voids.

Special curves and surfaces intersect at critical points and they too can be found and classified. Mathematically, they are known as *invariant manifolds* (including separatrices or "basin boundaries"). Some examples in fluid dynamics are *vortex cores, separation lines, attachment lines,* and *separation surfaces*. In molecular quantum mechanics, examples (via QTAIM) include *inter-atomic surfaces*, which exactly bound each atom and the *bond paths*, which precisely and unambiguously signal the presence of a chemical bond.

The topology of vector, scalar, and tensor fields is a unifying approach to understanding phenomena across much of science, engineering, and mathematics. It has been used for many years in aerodynamics, plasma physics, geophysics, quantum chemistry, ecology, celestial mechanics, and dynamical systems theory. More recently, it has found applications in nuclear physics, pattern recognition, medicine, data compression, data mining, human factors, visiometrics, and cosmology.

However, before "A Tool for Visualizing the Topology of Vector Fields" (by Globus, Levit and Lasinksi) analysis of field topology was primitive. It was performed manually and/or utilizing numerous separate and ill-fitting software tools designed for other purposes. The whole process was labor-intensive, error prone, and culminated in hand-drawn black-and-white 2D figures.

The work described in this paper changed all this. It introduced new, automated topological techniques, demonstrated them on real-world data, and described their ntegration into a production scientific and engineering visualization environment, FAST (Flow Analysis Software Toolkit). Using the topology module in FAST, for the first time, a scientist or engineer could automatically locate all critical points in any field computed on a multi-zone 3D overset mesh (the kind used most often in aerodynamical engineering calculations).

Once the critical points were located, they were classified and rendered in 3D using glyphs, which also displayed local approximations to their invariant manifolds. Then (optionally), the invariant curves and surfaces (vortex cores, separation lines, etc.) were found, classified, and rendered in 3D under the control of a variety of options.

Complete determination of the global 3D topology was not expected—16 years later, it is still an actively researched and unsolved problem. Nevertheless, the FAST topology module did a

complete and accurate job of classifying and rendering local topology, and much of the global topology of 3D vector and scalar fields.

The nominee paper moved topological analysis out of the realm of inaccurate results on "toy" problems and into the realm of robust results on real problems. It dramatically improved the quality, quantity, and breadth of field topology analyses performed in industry, academia, and government.

"A Tool for Visualizing the Topology of Vector Fields" has been applied to a broad range of disciplines, with over 200 citations in the literature. Some example applications, with relevant citations to the nominee paper in brackets, and no citation listed more than once in this entire document, are:

Theoretical fluid dynamics [8,30,49,73,150]. Applied aerodynamics, including the Columbia Accident Investigation [142], rockets and missiles [18,42,60], turbomachinery design [47,61], automotive engineering [50,167], and architecture [149]. Earth and space sciences, including climatology [6,94], oceanography [137,151], solar physics, and geophysics [115-117,165,177]. Applied mathematics, including dynamical systems theory [10,44,66,67,97,99,100,124,125], numerical analysis [9,51], and grid generation [23,78]. Image processing and pattern recognition [34,129,161,163,168,172]. Data compression [26,64,83,92,95,103,131,134]. Graph theory and computational geometry [87,101,141,155,186]. Data mining, visiometrics, and machine learning [17,113,126,136,158]. Human factors [41,43,96,105,154,181]. Quantum chemistry and molecular physics [90,112]. Cardiology [63,110]. And, of course, flow visualization [10,14,21, 39-40,57-59,79,85,86,88,91,104,111,121,179], scientific visualization [25,31,33,45,52,54,65,72, 89,146-147,160,162,182] and computer graphics [2-4,7,15-16,20].

The paper has also been cited in textbooks and surveys [16,76,81,107,113,114,120,123,128,184], master's and doctoral dissertations [67, 109, 135, etc.], in at least one patent [80], and in educational materials (courses, proposals, reading lists) [35,55,185,E1-E12]. It has been cited by researchers in the USA, Canada, Japan, Germany, France, Austria, Switzerland, the Netherlands, Norway, Sweden, the Czech Republic, Slovakia, Brazil, Venezuela, China and Egypt,.

Cumulative citations by year
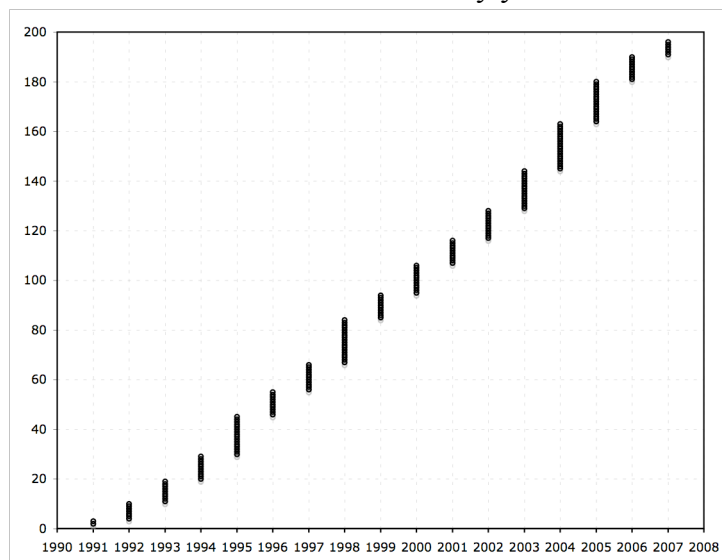
"A tool for visualizing the topology of three dimensional vector fields"

The following innovations are described in this paper—all for the first time:

1. Implementation and demonstration of software to automatically find, classify, track, and visualize critical points in vector (and scalar) fields in two and three dimensions. [71,93,97,100, 146,157,159,173,174,176]

2. Automatic detection and visualization of invariant manifolds (basin boundaries, separation lines, etc.) in vector and scalar fields. [48,75,82,104,130,138,164,170, 179,180]

3. Automatic detection and display of vortices in 2D and 3D flows. [19,24,27,28,29,32,56,62, 68,102,110,142,143,156,178]

4. Explicit graphical display of tensor-valued quantities. [5,12,22,37,53,69,70,77,84,109]

5. Feature display in 3D fields using specialized 3D icons (glyphs). [30,36,59,106,109,113,118, 127,128, 151,156,171,173]

6. Automatic calculation of initial conditions for computing integral curves (i.e automatic placement of "seed points" to generate particle traces or streamlines). [46,58,74,98,183]

7. Semi-automatic tracking and display of changes in the topology of numerically defined vector and scalar fields (visual bifurcation analysis). [9,38,89,108,119,144,166,169,175]

8. Integration of topological analysis into a production scientific visualization system. The software described was included in FAST. Written at NASA Ames and deployed worldwide, FAST won the 1995 NASA software of the year award. [1,11]

History and contributions by each author:

(1988) Inspired by the work of Tobak (NASA Ames), Abraham (UCSC), and Shaw (UCSC), Levit developed an interactive software system for dynamically detecting, classifying, and visualizing critical points, invariant manifolds, and elementary bifurcations of vector and scalar fields in two and three dimensions. It was the first system with any of these capabilities.

(1989) Levit publicly demonstrated his software at the *Conference on Scientific Applications of the Connection Machine*, in the main auditorium at NASA Ames Research Center. About 60 people attended, including V. Watson (NASA Ames).

A few days later, Watson invited Levit and Lasinski (Levit's branch chief at the time) to meet with Hesselink (Stanford University). Hesselink informed them that Hellman (his student) was doing similar work for a doctoral dissertation. Hesselink asked Levit to refrain from publication until Hellman finished his dissertation. Levit agreed.

(1990) Globus and Levit took Levit's prototype and integrated it into FAST as the "TOPO" module. Globus did most of this programming. (FAST won the 1995 NASA software of the year award)

Hellman and Hesselink published: "Surface representations of two and three-dimensional fluid flow topology" in *Proceedings: Visualization '90,* pages 6-13. IEEE Computer Society, 1990.

(1991) Globus, Levit, and Lasinski published, "A tool for visualizing the topology of three-dimensional vector fields." NASA Ames technical report RNR-91-017 and later in *Proceedings Visualization '91*, pages 33–40. IEEE Computer Society, 1991. Globus and Levit each wrote about half of the paper. Lasinski wrote the appendix.

Supporting Material

Supplement A: List of scientific and engineering literature citing the paper

<mark>Some papers citing "A tool for visualizing the topology of three-dimensional vector fields", by Al Globus, Creon Levit and Tom Lasinski. In Proc. of IEEE Visualization '91, pages 33-40 (1991) and/or NASA Ames Tech. Rept. RNR 91-017.</mark>

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[197](late addition) Turbulent Decay And Mixing Of Accelerated Inhomogeneous Flows Via Feature Analysis. S. Zhang and N. Zabusky. In: Symposium on Modeling and Simulation of Variable Density and Compressible Turbulent Mixing, Los Alamos National Laboratory (2005). www.ccs.lanl.gov/ccs2/msvdctm_symposium/docs/Zhang-talk1.pdf

[198](late addition) Topological Methods in Flow Visualization. G. Scheuermann, X. Tricoche. In: Visualization Handbook, C.D Hansen and C.R. Johnson eds., Elsevier pp.341-356. (2004) www.sci.utah.edu/~tricoche/papers/topology.pdf

[199](late addition) Vector and Tensor Topology Simplification, Tracking, and Visualization. X. Tricoche. Ph.D. Thesis, University of Kaiserslautern (2002). www.sci.utah.edu/~tricoche/papers/phd.pdf

Supplement B: List of educational materials citing the paper

Some course notes, reading lists, tutorials and proposals citing "**A tool for visualizing the topology of three-dimensional vector fields**" by Al Globus, Creon Levit and Tom Lasinski. In Proc. of IEEE Visualization '91, pages 33-40 (1991) and/or NASA Ames Tech. Rept. RNR 91-017.

[E1] ACM SIGGRAPH conference on Computer Graphics and Applications (1994,1995,1997)

[E2] IEEE Visualization conference tutorials (1993-1999)

[E3] Vector Field Visualization Project, Laboratory of Integrated Systems, Digital Systems Division, Politechnic School, University of Sao Paulo, Brazil. www.lsi.usp.br/~vectvis

[E4] Vector Field Visualization Course Notes. Lawrence Livermore National Laboratory. R. Crawfis (1995) www.llnl.gov/graphics/docs/VecVizNotes.pdf

[E5] Computación Gráfica III, Departamento de Computación y Tecnología de la Información Universidad Simón Bolívar (Venezuela) www.ldc.usb.ve/~vtheok/cursos/ci5322/stereo/Scientific-Visualizat.html (1999)

[E6] Technische Universität Wien, Institut für Computergraphik und Algorithmen, "Visualisierung Dynamischer Systeme" (Vienna, Austria). www.cg.tuwien.ac.at/research/vis/seminar9596/2-topo (1995-1996)

[E7] AMR Vortex Core/Tubes Visualization Research Plan, James Chen, Institute of Data Analysis and Visualization UC Davis muldoon.cipic.ucdavis.edu/~jchen007/Research/SV/AMR/ResearchPlan (2000)

[E8] Clustering and Segmentation of Adaptive Mesh Refinement Vector Field Data, James Chen, Institute of Data Analysis and Visualization, UC Davis. graphics.cs.ucdavis.edu/~jchen007/Research/VectorFieldClustering/FeatureExtraction_References.html (2001-2002)

[E9] Scientific Visualization HPC2N, Umeå Universit, Sweden, Department of Computing Science, "The course Scientific Visualization is part of the core curriculum of the Swedish National Graduate School in Scientific Computing" (1995-1999).

[E10] Topologie des Verhaltens in Dynamischen Systemen, Abteilung für Computergraphik Visualisierung Dynamischer Systeme. Technische Institut für Computergraphik und Algorithmen, Universität Wien (Austria) www.cg.tuwien.ac.at/research/vis/seminar9596/2-topo/literatur.html

[E11] CMP 260 - Computer Graphics. University of California, Santa Cruz. www.soe.ucsc.edu/~pang/260/w03/presentations/3Dseeding.ppt (2003)

[E12] Scientific Visualization CMPT 775, Computer Science Dept., Simon Fraser University, Vancouver British Columbia (2004) www.cs.sfu.ca/~torsten/Teaching/Cmpt878/reading.html

Supplement C: Information regarding author contributions

Return-Path: <aglobus@mail.arc.nasa.gov>
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  with ESMTP id 2388507 for clevit@mail.arc.nasa.gov; Wed, 27 Aug 2003 09:06:00 -0700
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  with ESMTP id 2388502; Wed, 27 Aug 2003 09:05:59 -0700
Date: Wed, 27 Aug 2003 09:08:19 -0700
Subject: principle authorship
Cc: creon@nas.nasa.gov, slanghoff@mail.arc.nasa.gov
To: chenze@nas.nasa.gov
From: Al Globus <aglobus@mail.arc.nasa.gov>
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Sorry for my slow response. I've been on vacation.

Creon was a solid 50% of the topology paper in question, perhaps more.
He wrote large sections of it (contrary to what I said on the phone a
week or so ago, but it was 12 years ago and my memory of the details is
coming back), although probably somewhat less than half. Most,
although not quite all, of the ideas were Creon's. Creon implemented
something very similar first, by himself, for polynomials. Key parts
of that code were used in the FAST TOPO module. Creon also rustled up
the datasets. My contribution was integrating the ideas and code into
the FAST environment, modifying the algorithms for curvilinear grids
(with Creon's guidance), much of the user interface, recoding some of
the numerical algorithms, a few ideas, and writing a bit more than half
the paper. Most of the code was mine. During the project Creon and I
worked together essentially every day including discussions, debugging,
examining the code, trying new versions of the program, and examining
various data sets. Creon also taught me CFD, critical point analysis,
numerical methods, and some curvilinear grid theory.

Al Globus
CSC at NASA Ames Research Center
http://www.nas.nasa.gov/~globus/home.html

Return-Path: <tal@llnl.gov>
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  by pony2pub.arc.nasa.gov (CommuniGate Pro SMTP 4.0.6)
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Date: Thu, 14 Aug 2003 10:32:23 -0700
From: Tom Lasinski <tal@llnl.gov>
Subject: Authorship of "A tool for visualizing the topology of three
X-Sender: tal@mail-lc.llnl.gov
To: slanghoff@mail.arc.nasa.gov
Cc: Al Globus <aglobus@mail.arc.nasa.gov>, chenze@nas.nasa.gov, Creon Levit
<creon@nas.nasa.gov>
Message-id: <5.0.0.25.2.20030814085411.068e77d0@mail-lc.llnl.gov>

Stephanie,

Greetings from Livermore.

I received the text below from Creon, and I generally agree with the
observations. I would like to add my own comments.

When this paper was written, I was Creon's Branch Leader and a technical monitor
for the sub-contract under which Al worked. My own contributions were indeed
minor, adding only some mathematical refinements to ideas that Creon and Al
developed and demonstrated numerically. It is my observation that Creon was in
fact the principal author in that the basic ideas, calculations, and coding for
this paper came from him. He was the first person in my Branch to realize that
the stationary point analysis could be used to assist in the visual analysis of
flow fields. Furthermore, he was clearly the driver for creating a
visualization tool using topological analysis. From my perspective, Al's
contribution was to take these ideas and implement them in what was then the
primary visualization tool (FAST, I believe) supported by the Branch. That
effort enabled Creon and Al to demonstrate topological visualization analysis on
a large number of existing flow simulations and to make that capability
available to a large number of users in a familiar context.

I have an additional comment. Scientific research is increasingly a team effort;
indeed, I would argue that scientific success in most areas requires sound team
work. I am concerned that rules such as "there must be only one senior author"
will disparage team-written papers of significant importance and discourage
future team work.

Regards,

Tom

==

According to the announcement soliciting nominations for the H. Julian Allen award:

"the senior author must be an Ames civil service employee, NRC postdoctoral
fellow, or resident Ames staff member."

In the case of the proposed nomination "A tool for visualizing the topology of three-dimensional vector fields" by Al Globus, Creon Levit and Tom Lasinski, there was no single senior author. There were two: Globus and Levit. They are listed in alphabetical order, as is the convention. Lasinski, the junior author, is listed last.

I am fairy certain that both Globus and Lasinski would attest to the following:

Levit is one of the two senior authors. He (Levit):

1) wrote about half of the paper.
2) did about half of the work described in the paper.
3) came up with the initial idea for the project and did the initial R&D.
5) wrote and debugged, alone, the initial computer implementation of the core numerical algorithms and the graphics in both two and three dimensions.
6) provided this core code, which was then incorporated, with necessary enhancements, into the FAST visualization framework by Globus.

Levit was the primary author of the parts of the paper corresponding to his "half" of the work, and similarly for Globus. Lasinski wrote the proof in the appendix. Levit also wrote the bibliography, which might sound insignificant, but in this case was actually fairly deep. It was later expanded into a technical report, subsequently used in several courses in scientific visualization and cited by others.
…

It is known that when a principal author's name occurs later in the alphabet, there is ambiguity. The consequence of this ambiguity has been the subject of scholarly debate (see references [1-3]).

references:

[1] Darwin a better name than Wallace? T. Tregenza. Nature 385, 480 (1997).

[2] Unequal letters. K. T. Jaekel. Nature 386, 643 (1997).

[3] Alphabetical listing and citation rates. M. Shevlin & M. N. O. Davies. Nature 388, 14 (1997)

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Supplement D: Some figures from literature citing the paper

A sampling of figures taken from literature citing: **A tool for visualizing the topology of three-dimensional vector fields**. Al Globus, Creon Levit and Tom Lasinski. Proc. of IEEE Visualization '91, pages 33-40, and/or NASA Ames Tech. Rept. RNR 91-017 (1991)

Topology Preserving Top-Down Compression of 2D Vector Fields Using Bintree and Triangular Quadtrees

Suresh K. Lodha, *Member*, *IEEE*, Nikolai M. Faaland, and Jose C. Renteria

QU: 60.05%   QU: 25.40%*   QC: 60.00%   QC: 32.70%*
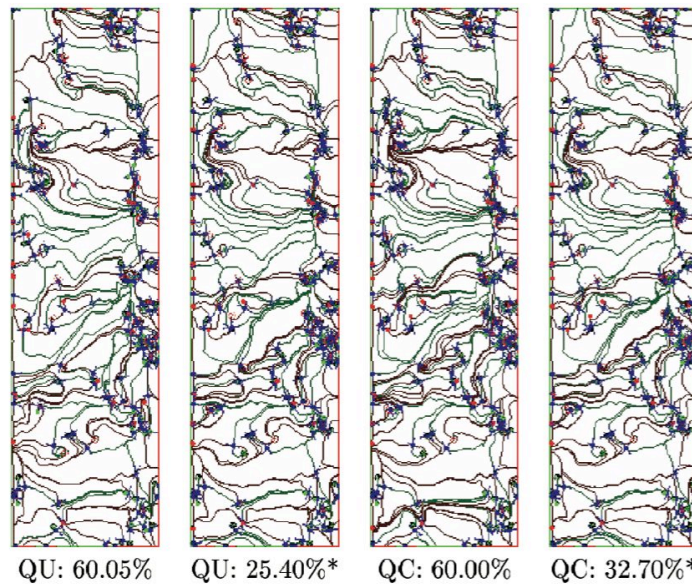
Fig. 10. Topology visualization at varying levels of compression of the Skin Friction with the bintree unconstrained (BU), bintree constrained (BC), quadtree unconstrained (QU), and quadtree constrained (QC). The asterisk indicates the cutoff point.

Image-Guided Streamline Placement

Greg Turk, University of North Carolina at Chapel Hill
David Banks, Mississippi State University

Figure 7: Chains of arrows indicate wind direction and magnitude over Australia. The arrows were deposited along streamlines created by streamline optimization. Higher velocity is indicated by larger arrows. The vector field data was calculated using a numerical weather model.

Stream Line and Path Line Oriented Topology for 2D Time-Dependent Vector Fields

Holger Theisel *
MPI Informatik Saarbrücken

Tino Weinkauf †
Zuse Institute Berlin

Hans-Christian Hege ‡
Zuse Institute Berlin

Hans-Peter Seidel §
MPI Informatik Saarbrücken

(a) LIC images at 3 different time slices.

(b) Tracking the locations of critical points as stream lines (red/blue/yellow); local bifurcations: Hopf bifurcations (green spheres), fold bifurcations (gray spheres).

(c) Global bifurcations: saddle connections (red/blue flow ribbons), tracked closed stream lines (green surfaces).
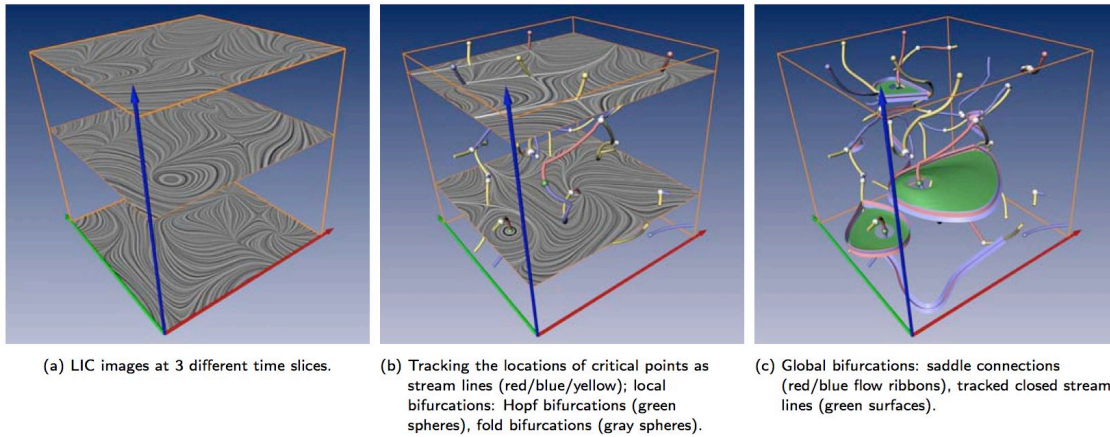
Figure 1: Stream line oriented topology of a 2D time-dependent vector field.

(c)

(d)

(e)
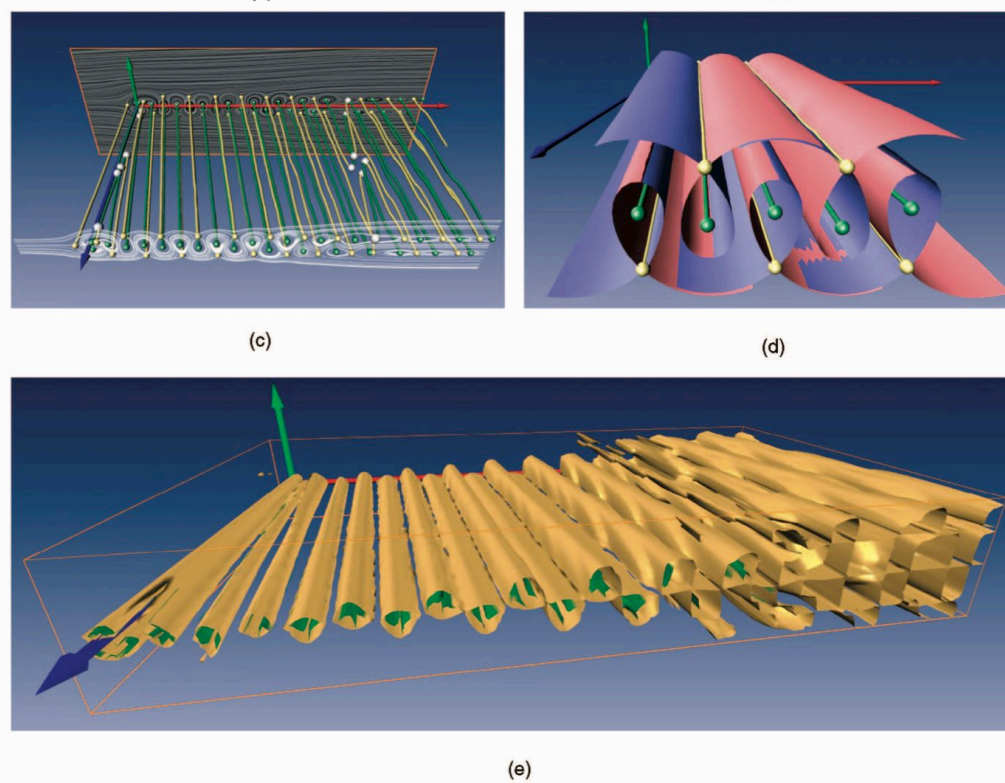
Fig. 17. 2D Flow behind a circular cylinder. (a) Stream lines of s correspond to the stream lines in v. (b) Stream lines of p correspond to the path lines in v. (c) Stream line oriented topology after subtracting a constant vector field. (d) Stream lne oriented topology with separation surfaces (closeup). (e) Path line oriented topology.

Detecting and Visualizing Local Bifurcations in 2D Time-dependent Vector Fields

Guanjie Yang, Keqin Wu, Haixia Shang

Department of Computer Science, Ocean University of China, Qingdao 266071,China
yguanjie@ouc.edu.cn, wukeqin@ouc.edu.cn
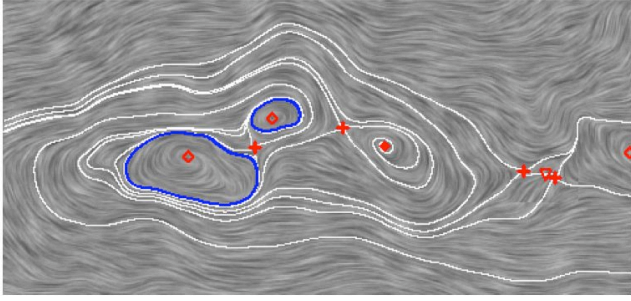
Fig. 4. **Topology skeleton and streamlines of V at the time step t$_i$.**
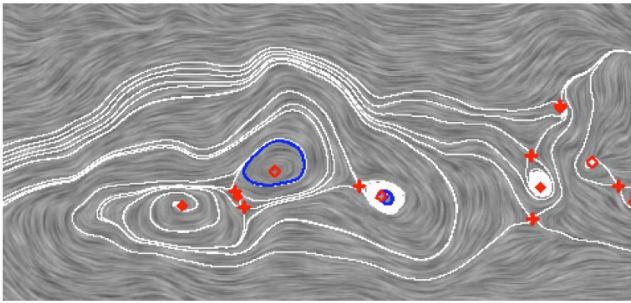
Fig. 5. **Topology skeleton and streamlines of V at the time step t$_{i+1}$.**
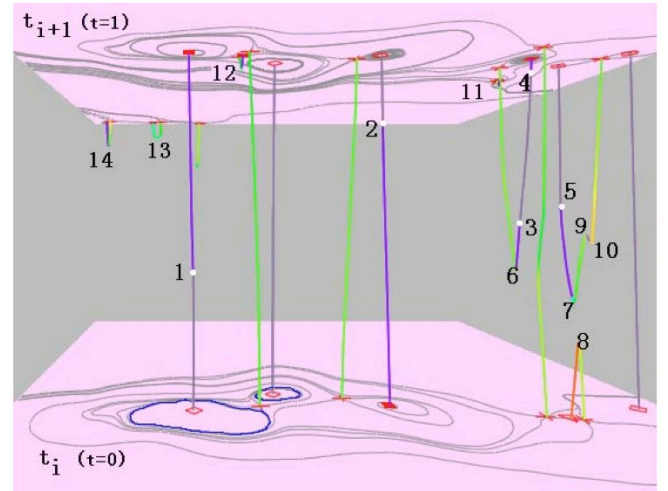
Fig. 6. **Topology tracking and bifurcation visualization based on the HSV color model. In the figure, Five Hopf bifurcations (marked as 1 to 5) and nine Saddle-Node bifurcations (marked as 6 to 14) occur between the two time slices t$_i$ and t$_{i+1}$, the exact locations of them are detected (e.g. the corresponding locations of 5 Hopf bifurcations are: t[1]=0.380000, t[2]=0.811500, t[3]=0.514000, t[4]=0.946470, t[5]=0.568100.)**

Grid-Independent Detection of Closed Stream Lines in 2D Vector Fields

Holger Theisel[1]   Tino Weinkauf[2]   Hans-Christian Hege[2]   Hans-Peter Seidel[1]

[1] MPI Informatik, Saarbrücken, Germany – {theisel,hpseidel}@mpi-sb.mpg.de
[2] Zuse Institute Berlin (ZIB), Germany – {weinkauf,hege}@zib.de
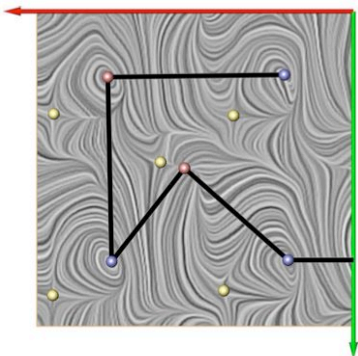
(a) Polygon ℓ connecting all sources/sinks and one boundary point.
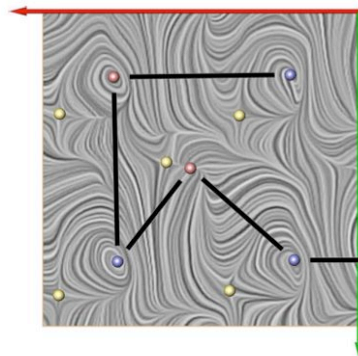
(b) Polygon ℓ splitted around the critical points.
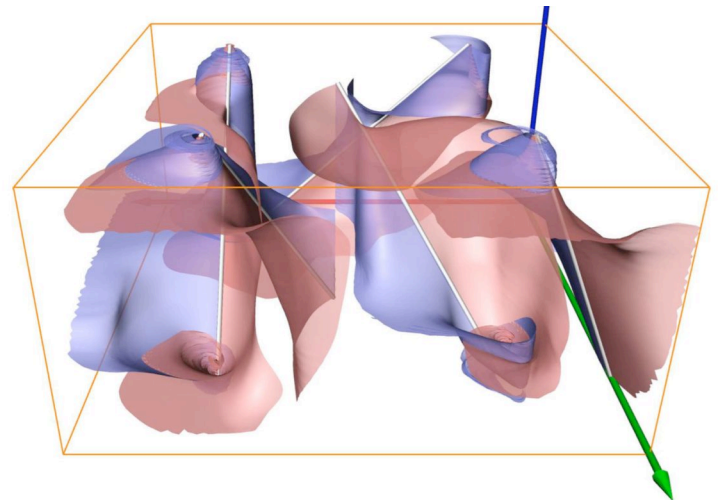
(a) Intersecting stream surfaces of all 5 seeding curves shown at once. They must be treated separately as they have overlapping z-value ranges.

Extracting Higher Order Critical Points
and Topological Simplification of 3D Vector Fields

Tino Weinkauf *   Holger Theisel †   Kuangyu Shi ‡   Hans-Christian Hege §   Hans-Peter Seidel ¶
ZIB Berlin   MPI Saarbrücken   MPI Saarbrücken   ZIB Berlin   MPI Saarbrücken
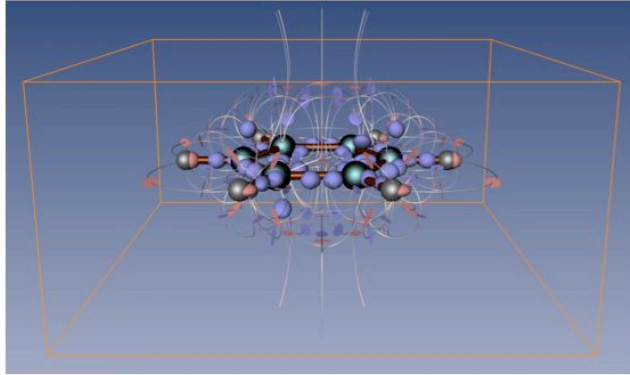
(a) 184 first order critical points. The box around the molecule represents the chosen area for topological simplification.
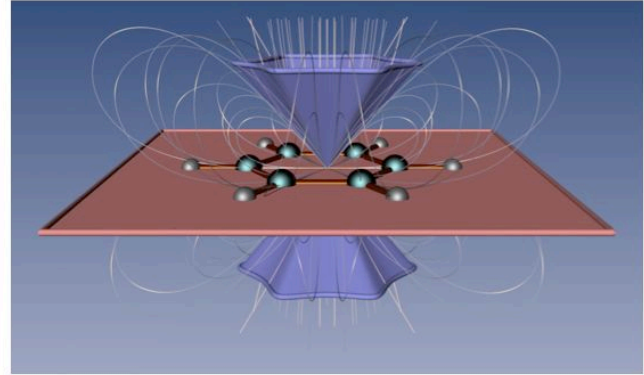
(b) Topologically simplified representation with one higher order critical point elucidates the far field behavior of the benzene.

Figure 1: Topological representations of the electrostatic field of the benzene molecule.

Boundary Switch Connectors for Topological Visualization of Complex 3D Vector Fields

T. Weinkauf[1], H. Theisel[2], H.-C. Hege[1] and H.-P. Seidel[2]

[1] Zuse Institute Berlin (ZIB), Berlin, Germany — {weinkauf, hege}@zib.de
[2] MPI Informatik, Saarbrücken, Germany — {theisel, hpseidel}@mpi-sb.mpg.de
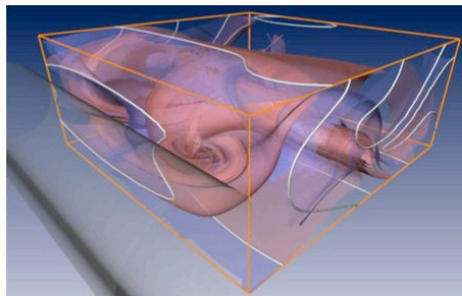
(a) Separation surfaces emanating from boundary switch curves and saddles.
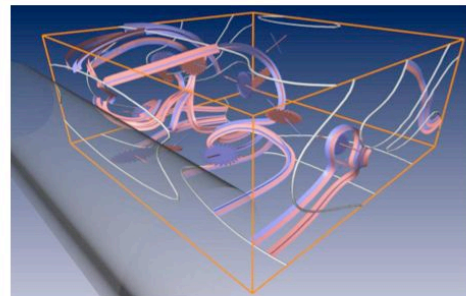
(b) Boundary switch connectors between boundary switch curves.
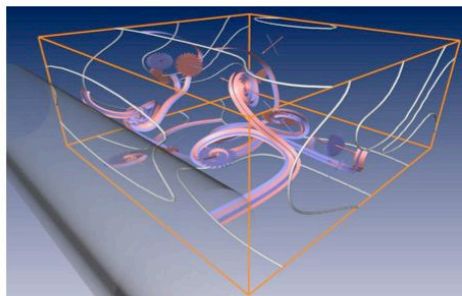
(c) Boundary switch connectors between saddle points and boundary switch curves.
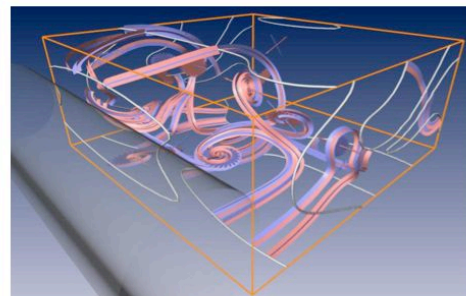
(d) Saddle connectors and both types of boundary switch connectors.

Figure 14: *Flow behind a circular cylinder. Different topological representations.*

Saddle Connectors - An Approach to Visualizing the Topological Skeleton of Complex 3D Vector Fields

Holger Theisel *
MPI Informatik Saarbrücken

Tino Weinkauf[†]
Zuse Institute Berlin

Hans-Christian Hege[‡]
Zuse Institute Berlin

Hans-Peter Seidel [§]
MPI Informatik Saarbrücken
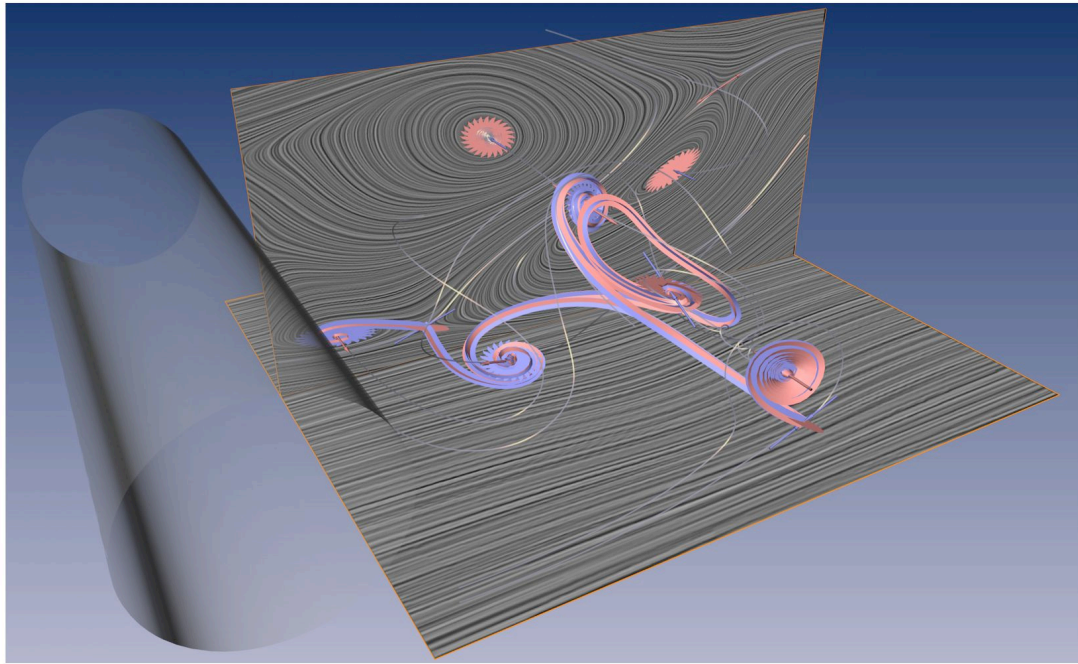
Figure 13: Flow behind a circular cylinder. 13 critical points and 9 saddle connectors have been detected and visualized. Additional LIC planes have been placed to show the correspondence between the skeleton and the flow.

Feature Flow Fields

H. Theisel[†] and H.-P. Seidel[‡]

Max-Planck-Institut für Informatik, Stuhlsatzenhausweg 85, 66123 Saarbrücken, Germany
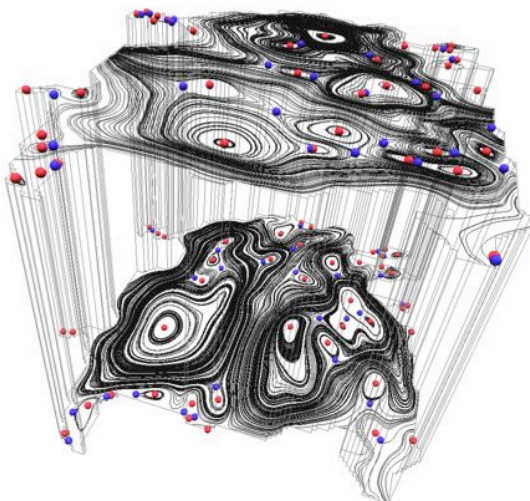
Figure 7: *Critical points and stream lines of* **v** *at the time steps* t_0 *and* t_{24}.
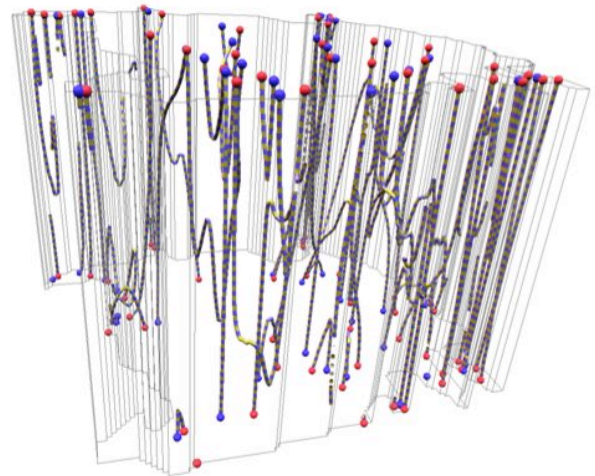
Figure 9: *Critical points and stream lines of* **f** *at the time steps* t_0 *and* t_{24}.

Flow Topology Beyond Skeletons: Visualization of Features in Recirculating Flow

Ronald Peikert and Filip Sadlo

Computer Graphics Laboratory, Computer Science Department,
ETH Zurich, Switzerland, {peikert, sadlo}@inf.ethz.ch
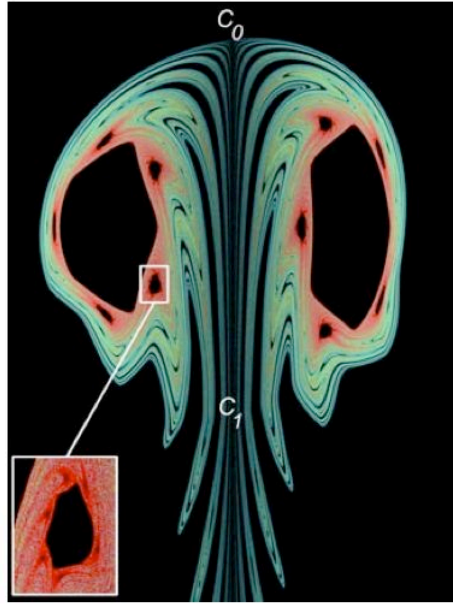
Fig. 6. Hill's spherical vortex with swirl ($\omega = 2\pi$) and tilt ($\epsilon = 0.313$). Slice of the stable manifold of the critical point at $(0, 0, 1)$.
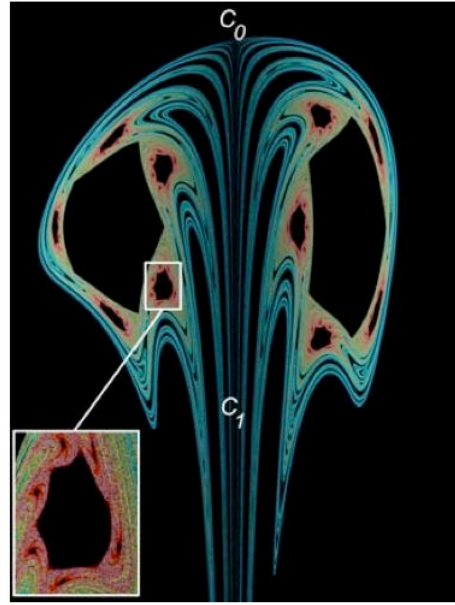
Fig. 7. Inner part $\mathbf{u}_{\epsilon\omega}^{i}$ of Hill's spherical vortex with swirl ($\omega = 2\pi$) and tilt ($\epsilon = 0.442$).
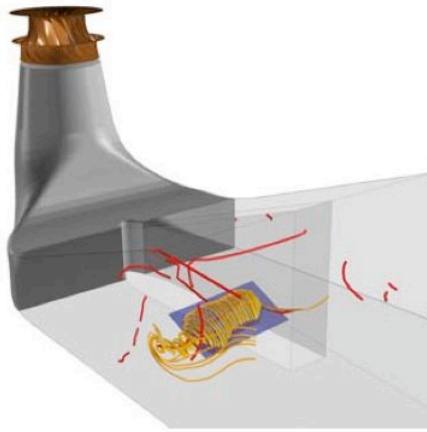
Fig. 8. Overview of the flow in the draft tube. Poincaré section used for Figure 10 shown as blue rectangle, vortex core lines shown in red.
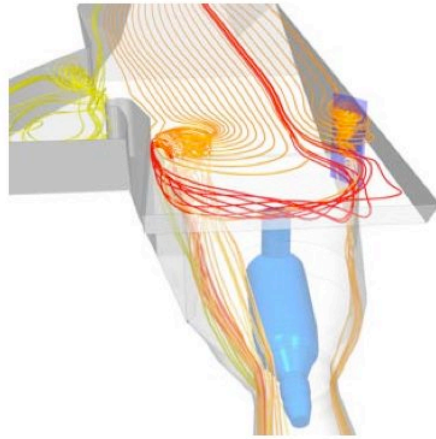
Fig. 9. Overview of the flow in the river power plant. Poincaré section used for Figure 11 shown as blue rectangle.

Visualization of Intricate Flow Structures for Vortex Breakdown Analysis

Xavier Tricoche*
University of Utah

Christoph Garth
University of Kaiserslautern

Gordon Kindlmann
University of Utah

Eduard Deines
University of Kaiserslautern

Gerik Scheuermann
University of Leipzig

Markus Ruetten
DLR Goettingen

Charles Hansen
University of Utah
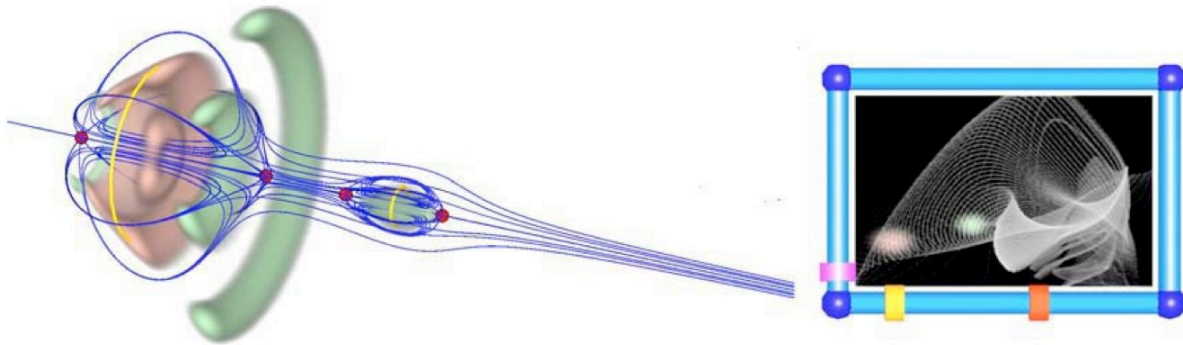
Figure 1: Vortex breakdown bubble in numerical simulation of a cylindrical container. Flow topology is illustrated with stagnation points (red), singularity paths (yellow), and streamlines (blue) on three axially oriented cutting planes. Volume rendering illustrates additional aspects of flow structure, using a two-dimensional transfer function (widget, right) of a Jacobian-related invariant (horizontal axis) and vorticity (vertical axis).

Tracking of Vector Field Singularities in Unstructured 3D Time-Dependent Datasets

Christoph Garth
Dept. of Computer Science
University of Kaiserslautern

Xavier Tricoche
Scientific Computing and Imaging Institute
University of Utah

Gerik Scheuermann
Inst. of Computer Science
University of Leipzig
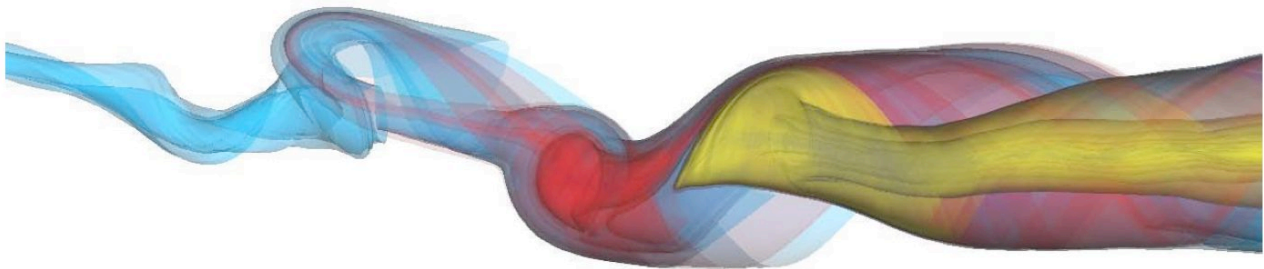
Figure 1: Illustration of complex vortex breakdown in a single timestep of the delta wing dataset. Transparently rendered separation surfaces originating at stagnation (saddle) points related to vortex breakdown on the delta wing (red and yellow). The blue stream surface originates at the tip of the wing and wraps the vortex core up to the breakdown point. The stream surfaces are computed using the approach described in [3]. This timestep was singled out by looking for interesting configurations of the complex vortex breakdown on the left side of the delta wing (cf. Section 6 and Figure 6 right).

Galilean Invariant Extraction and Iconic Representation of Vortex Core Lines

J. Sahner, T. Weinkauf, H.-C. Hege

Zuse Institute Berlin (ZIB), Berlin, Germany — {sahner, weinkauf, hege}@zib.de
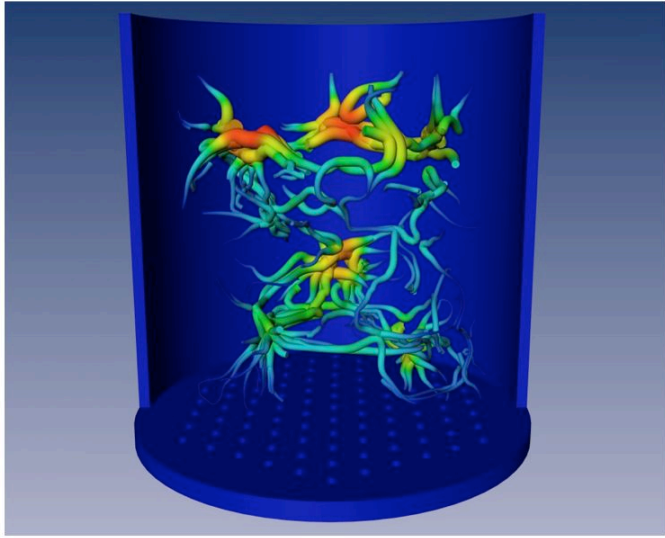
(c) Galilean invariant vortex core lines.
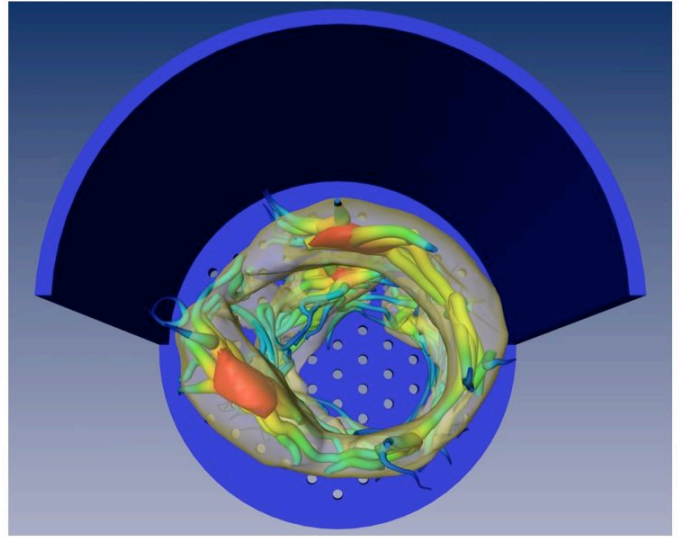
(d) Comparison between λ_2-isosurfaces and our vortex core lines. View from top.

Figure 5: *Bubble chamber. Vortex core lines extracted, colored and scaled according to λ_2. Same colormap as in figure 4.*

Extraction and Visualization of Swirl and Tumble Motion from Engine Simulation Data

Christoph Garth[1], Robert S. Laramee[2], Xavier Tricoche[3], Jürgen Schneider[4], and Hans Hagen[5]

[1] Visualization Group, Univ. of Kaiserslautern (garth@informatik.uni-kl.de)
[2] Dept. of Computer Science, Univ. of Wales (r.s.laramee@swansea.ac.uk)
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[4] AVL, Graz (juergen.schneider@avl.com)
[5] Visualization Group, Univ. of Kaiserslautern (hagen@informatik.uni-kl.de)
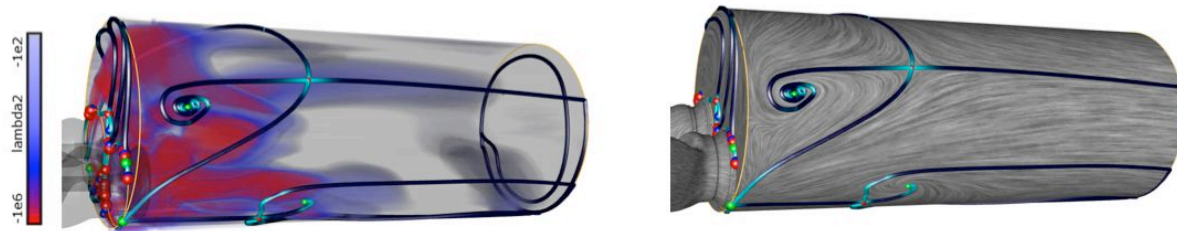
Fig. 3. Visualization of swirl motion using boundary topology. Critical points are colored by type (cf. Fig. 2), and separatrix color varies with separation/attachment behavior from dark blue (weak) to cyan (strong). Separatrices indicate the separation between neighboring vortices on the boundary. (Left) Combination with volume rendering with a transfer function of λ_2 only. On the bottom left of the cylinder, the recirculation zone causes a non-ideal off-center rotation, as visualized by topology. (Right) In combination with LIC.
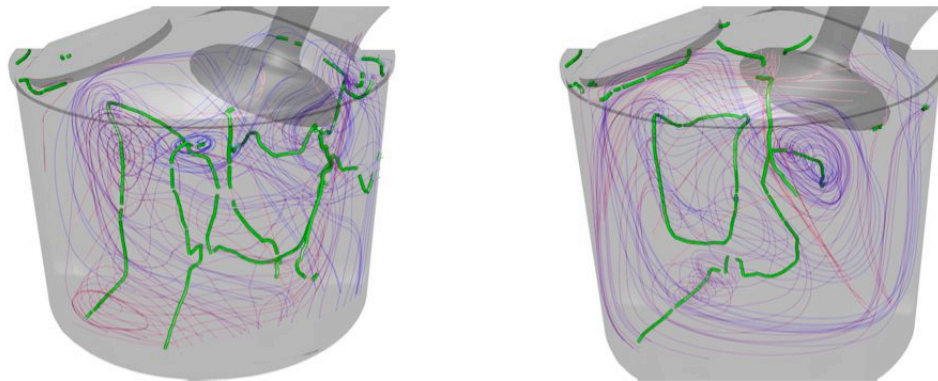
Fig. 5. Two frames from an animation of the tumble motion simulation. Cutting plane topology is applied to visualize flow field structures in the plane orthogonal to the tumble axis. Color of separatrices varies from blue to red on successive cutting planes. Tumble-like flow structures emerge clearly from the otherwise incoherent lines. The paths of critical points over the cutting plane continuum are displayed in green. In the last frame (right), the diagonal main tumble axis can be observed together with a large recirculation zone (closed path on the left).

Flow Visualization for Turbomachinery Design

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Abstract

Visualization of CFD data for turbomachinery design poses some special requirements which are often not addressed by standard flow visualization systems. We discuss the issues involved with this particular application and its requirements with respect to flow visualization.

Aiming at a feature-based visualization for this task, we will examine various existing techniques to locate vortices. The specific flow conditions for turbomachines demonstrate limitations of current methods. Visualization of turbomachinery flow thus raises some challenges and research topics, particularly regarding feature extraction.

1 Introduction

Water turbines used in hydroelectric power plants are large machines (typical runner diameter 3-7 m, Fig. 1) manufactured and designed individually for the specific conditions of the installation and requirements of the customer. Today, efficiencies exceed the level of 93%. A thorough introduction to hydraulic machines can be found in [1], a brief overview in [2].

During the design process, Computational Fluid Dynamics (CFD) is routinely used for optimization and comparison [3]. To investigate details in the flow and analyze its response to small changes of the machine geometry, visualization of the 3D flow in its proper spatial relationship with the channel geometry is crucial. A representative flow is shown in Fig. 2.

Figure 1: *Simulation model of a Kaplan turbine runner, a type of water turbine often used in river power plants. This case study describes issues of visualizing results of CFD simulations for the design of such water turbines.*

Figure 5: *The apparent vortex core is depicted by a circular stream surface around it. The place where real valued eigenvector is parallel to the flow is marked by the black line.*

Topology-guided Visualization of Constrained Vector Fields

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[1] ETH Zurich, Switzerland `peikert@inf.ethz.ch`
[2] ETH Zurich, Switzerland `sadlo@inf.ethz.ch`
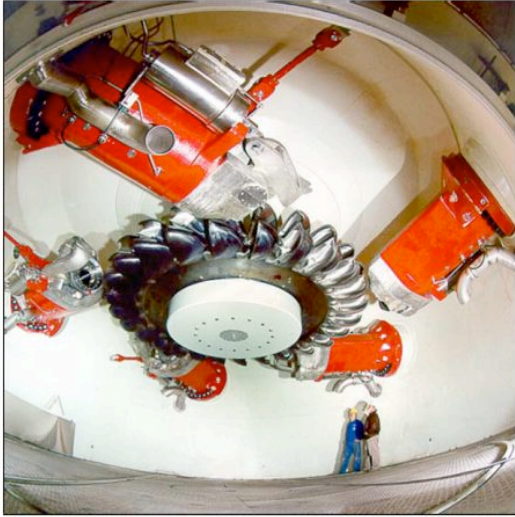
Fig. 2. Pelton turbine with five injectors.
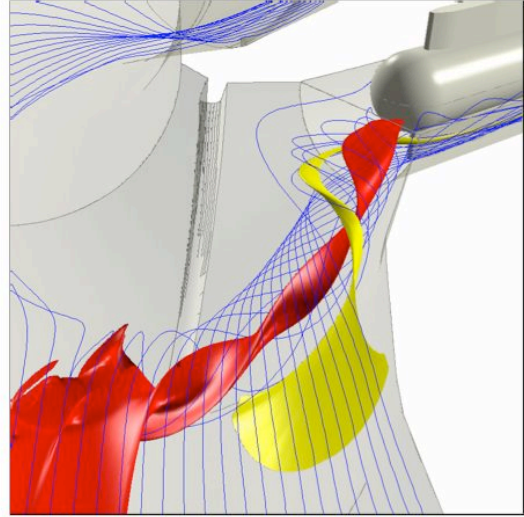
Fig. 3. Two vortices extending from the ring distributor into the first (of six) injectors

.
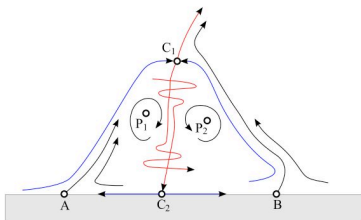
Fig. 1. Sketch of typical recirculation zone with two critical points of type spiral saddle (C_1, C_2) and one periodic orbit (P_1, P_2) involved. 1D manifolds (red curves) nearly meet. 2D manifolds (shown as blue curves) have a strong spiralling component.
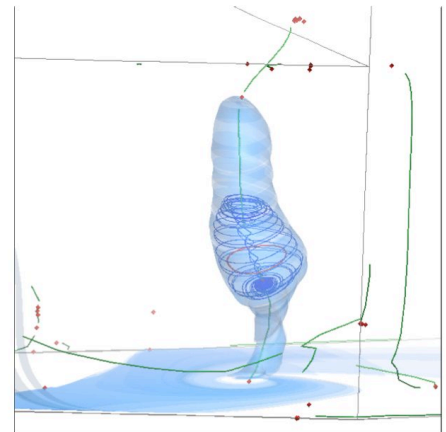
Fig. 8. "Tornado-type" separation and vortex in the draft tube dataset. Streamsurface (transparent blue) starts at saddle and goes upstream enclosing an open vortex-breakdown bubble (blue streamline) that contains a periodic orbit (red). Critical points are colored red and vortex core lines green.

Visual Analysis of Differential Information

Helwig Hauser, `Hauser@VRVis.at`

VRVis Research Center in Vienna, Austria,
`http://www.VRVis.at/`
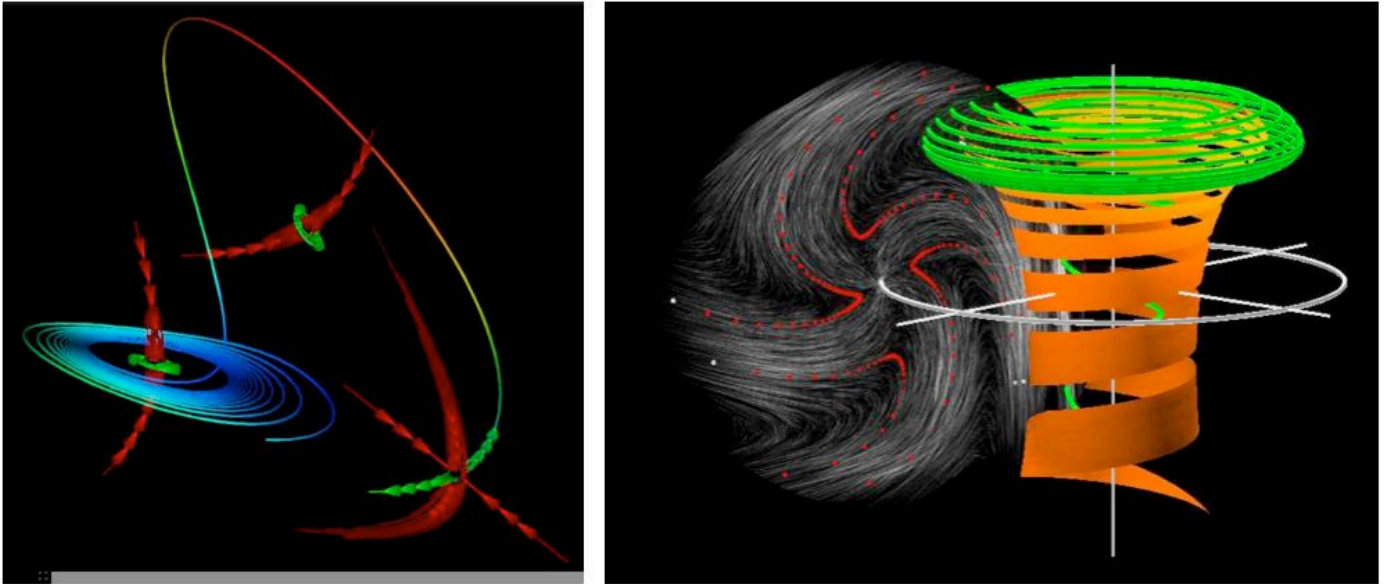
Figure 6: Topology-based visualization of a 3D dynamical system (left side [32]). Visualization of a periodic dynamical system in 3D based on a Poincaré map (right side [34])
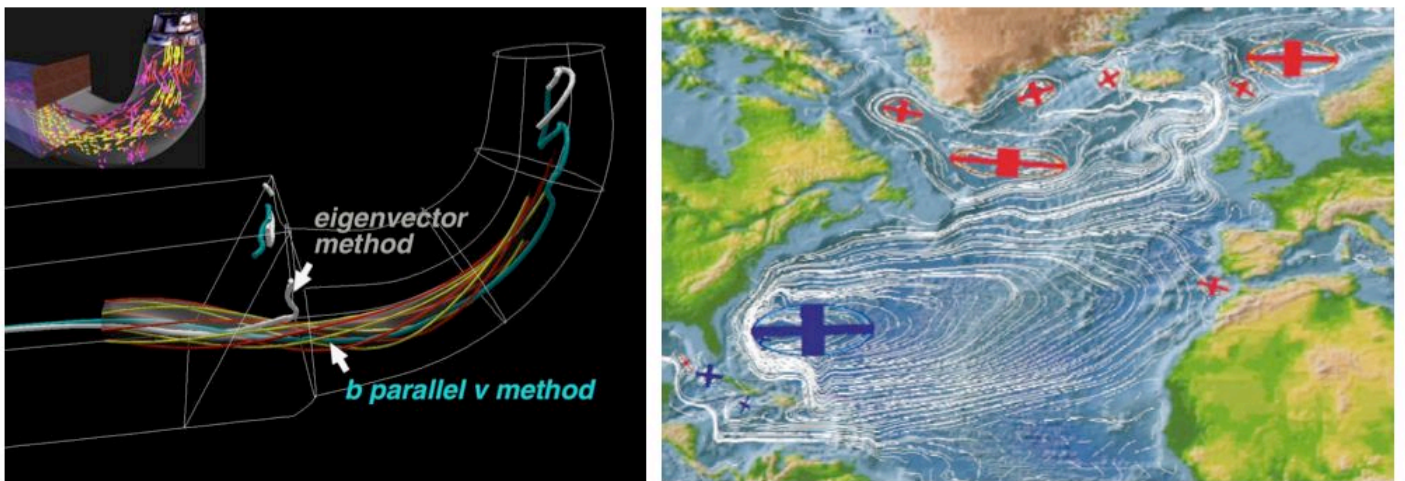
Figure 7: The parallel vector technique [38] applied to flow through a draft tube in turbomachinery design (left image, image courtesy by M. Roth et al., ETH Zürich [46]); Sample result from a geometric vortex extraction technique (right image, image courtesy by I. Sadarjoen et al., Delft University [48]).

Structure of a Supersonic Three-Dimensional Cylinder/Offset-Flare Turbulent Interaction

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U.S. Air Force Wright Laboratory, Wright–Patterson Air Force Base, Ohio 45433-7913

and

J. R. Edwards[‡]

North Carolina State University, Raleigh, North Carolina 27695
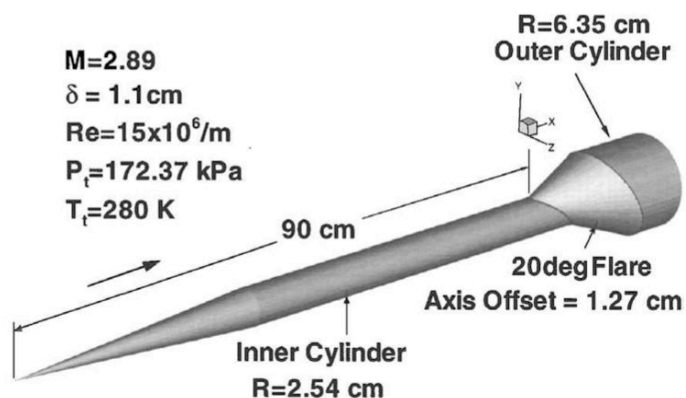
Fig. 1 Geometry of cylinder/offset-flare juncture.
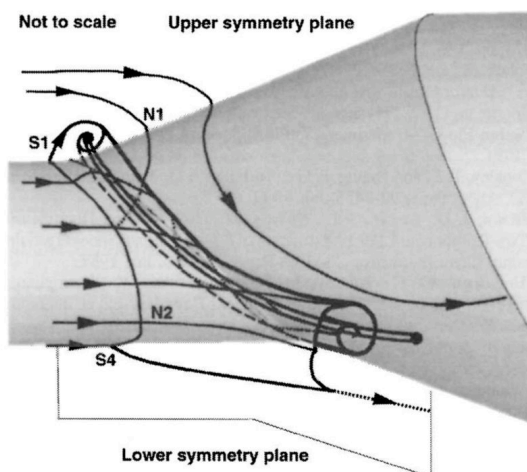
Fig. 13 Flowfield schematic in terms of principal vortical structure.
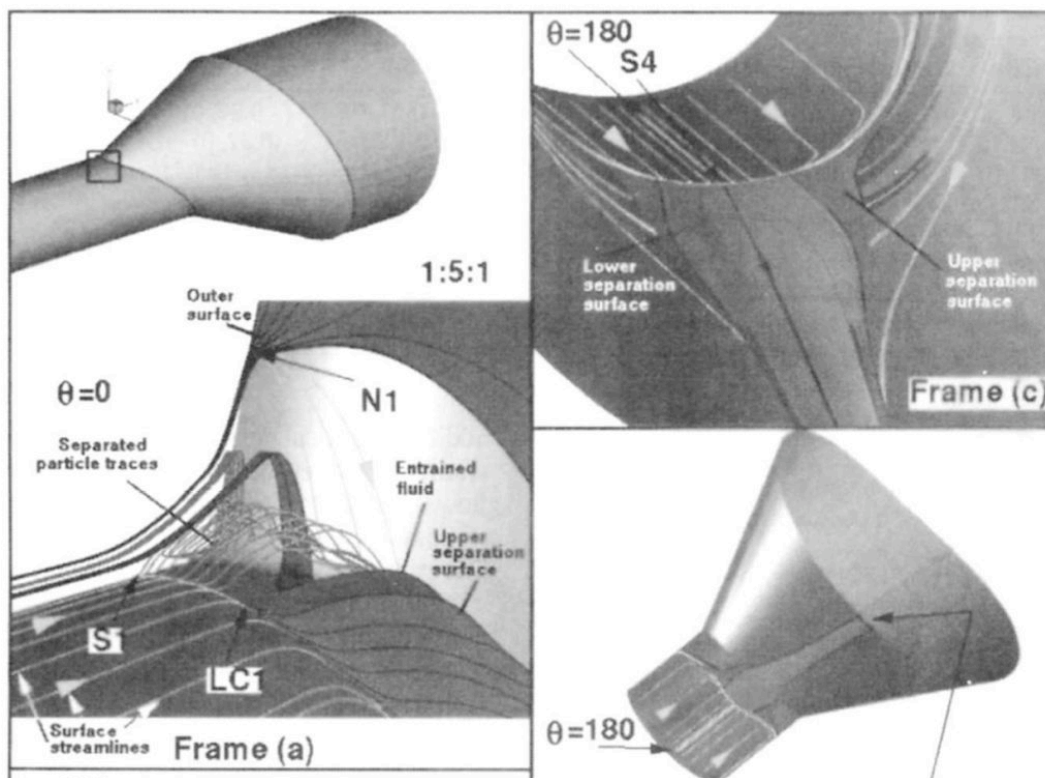
Flow Topology About An Orbiter Leading Edge Cavity At STS-107 Reentry Conditions

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and

Timothy A. Sandstrom[§]

NASA Ames Research Center, Moffett Field, CA 94035

b. Windward View
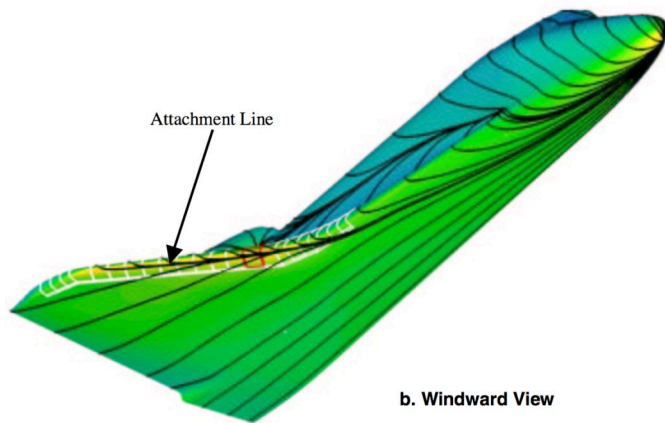
Figure 2. SB9, Smooth Body Orbiter surface streamlines with color-shaded wall temperature contours. The wing leading edge panels are shown outlined in white, with RCC panel 9 outlined in red. Wall Temperature color shading ranges from blue-green-yellow-red with increasing temperature.
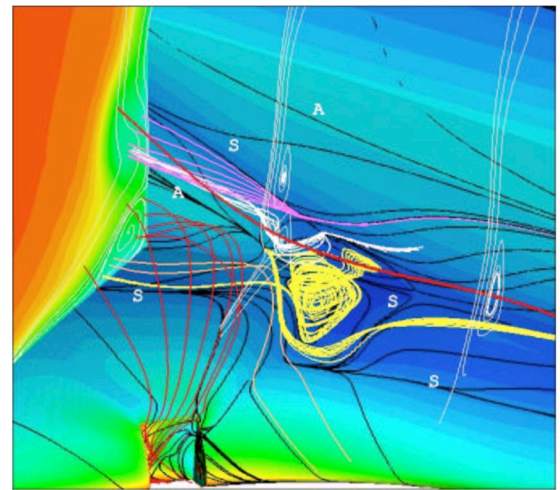
Figure 12. WP9V, Whole Panel 9 Vented Case, Flow Structures External to Cavity.
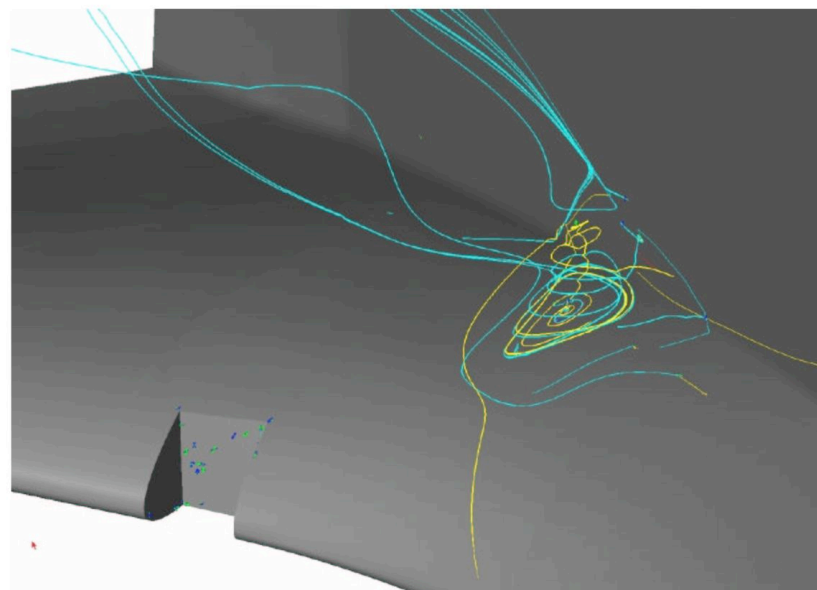
Figure 13. WP9V, Whole Panel 9 Vented Case, External Topology Features.

Many-to-Many Feature Matching for Structural Pattern Recognition

Muhammed Fatih Demirci
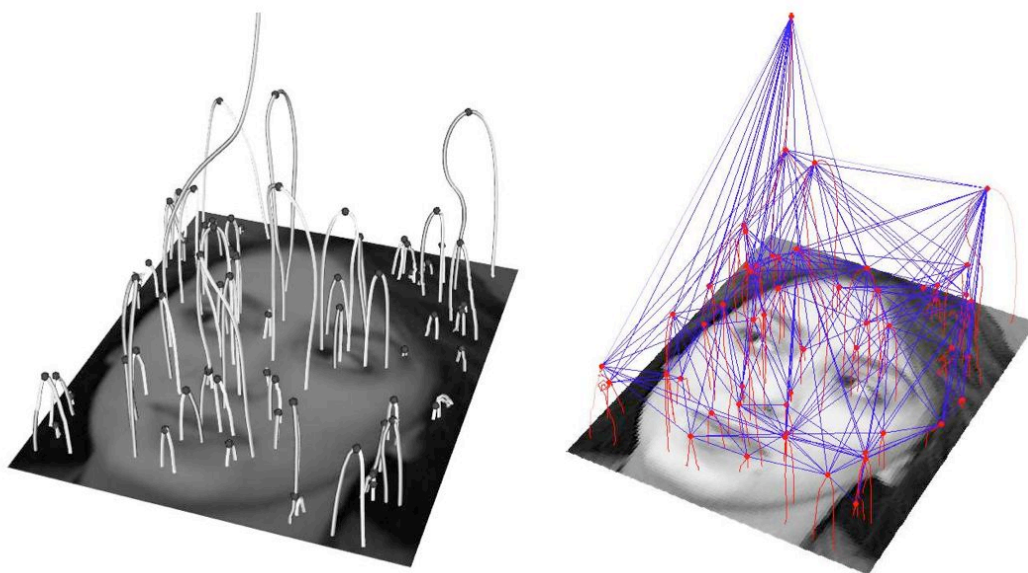
Figure 7.3: The right image shows the DAG obtained from applying Algorithm 7 to the critical paths and top points of the face in the left.

Figure 7.4: Sample faces from 20 people.

Visualization techniques for 3D vector fields: an application to electrostatic fields of molecules

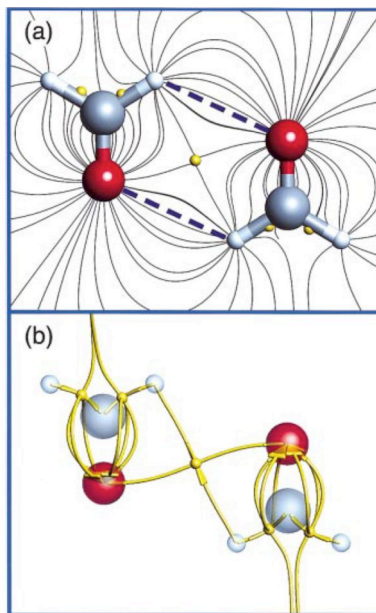By Susumu Handa*, Hiroshi Kashiwagi and Toshikazu Takada

Figure 1. Electrostatic field of a dimer of formaldehydes. (a) The saddle points (yellow balls) between atoms having the same signs. (b) The conventional topological skeleton is not able to illustrate the electrostatic interactions between atoms having opposite signs, which are drawn by the dotted lines in (a).
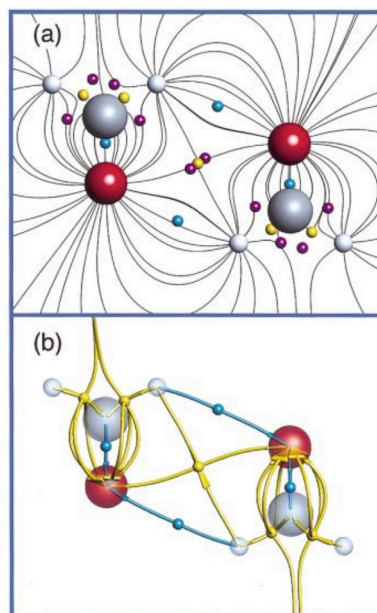
Figure 2. Extended critical points and topological skeleton curves. In addition to the saddle points (yellow), two kinds of dynamic critical points are found in (a). The minimum extreme points (cyan) are shown as expected between oppositely charged atoms. On the other hand, the maximum extreme points (magenta) are found near the saddle points.
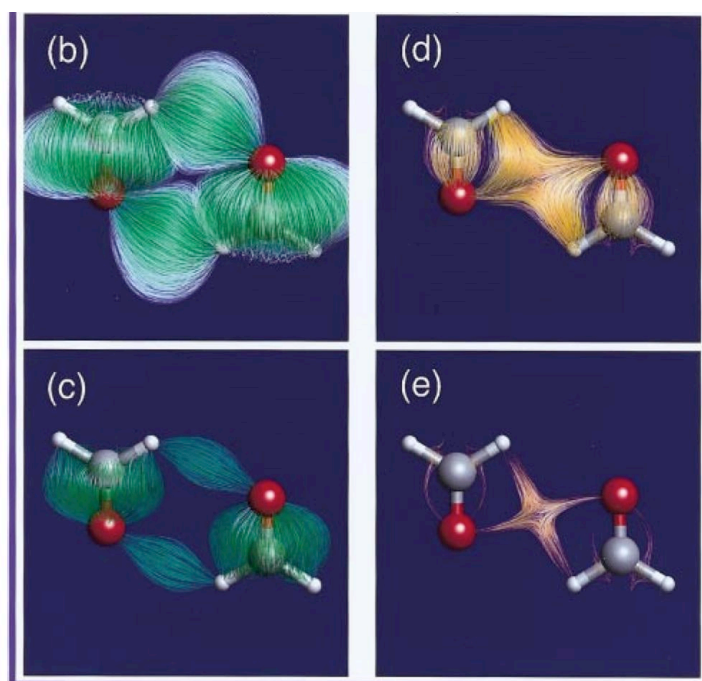
Figure 6. Selective visualization of electrostatic fields. (a) shows the whole domain illustrated as flow textures. In (b) and (c), $|v|^2$ is used to evaluate the selective function. The selected regions become narrow when specifying larger threshold values of the function, highlighting the electrostatic interactions between atoms having opposite signs. κ is used as the function values in (d) and (e), extracting the regions around the saddle points between atoms having the same sign.

Ocean Flow Visualization
in Virtual Environment

ZhanPing Liu   Robert James Moorhead   Sean Bernard Ziegeler

Visualization Analysis & Imaging Laboratory

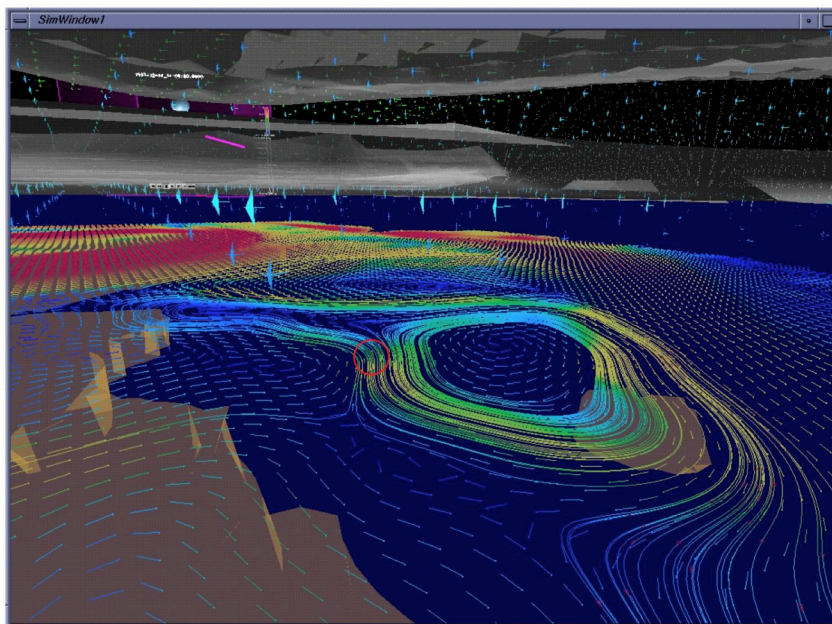NSF Engineering Research Center, Mississippi State University, MS
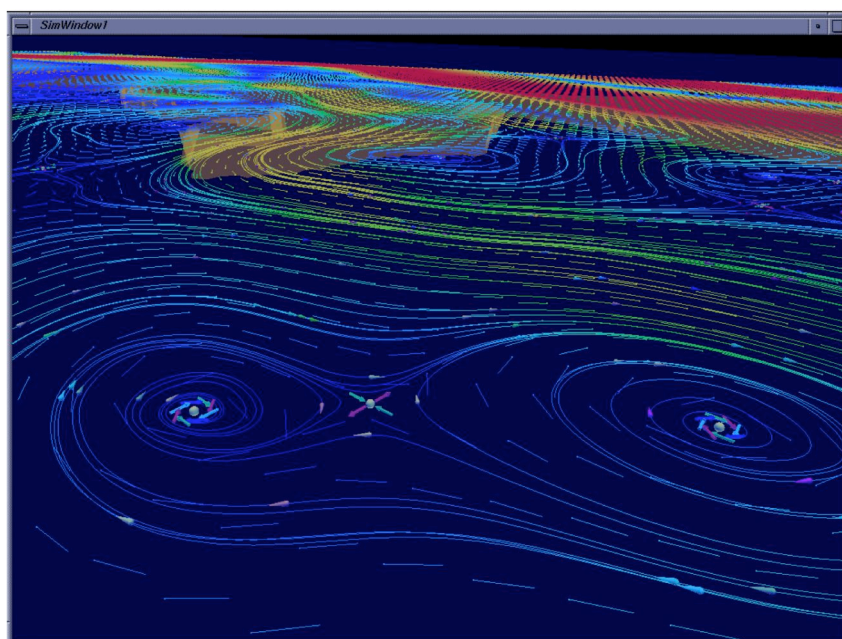
Fig. 17. Seeder based streamlines in CAVE

Fig. 25. Flow topology depicted with streamlines and glyphs.

Vector Field Visualization of Magnetospheric Dynamics

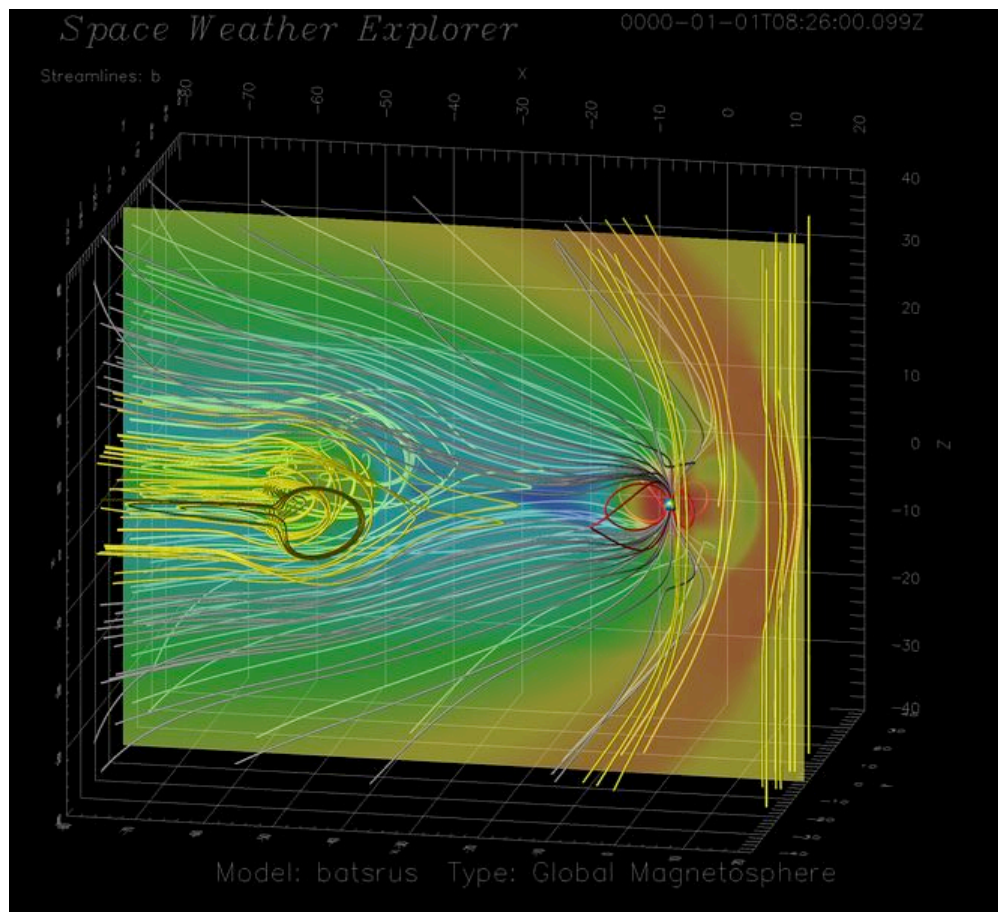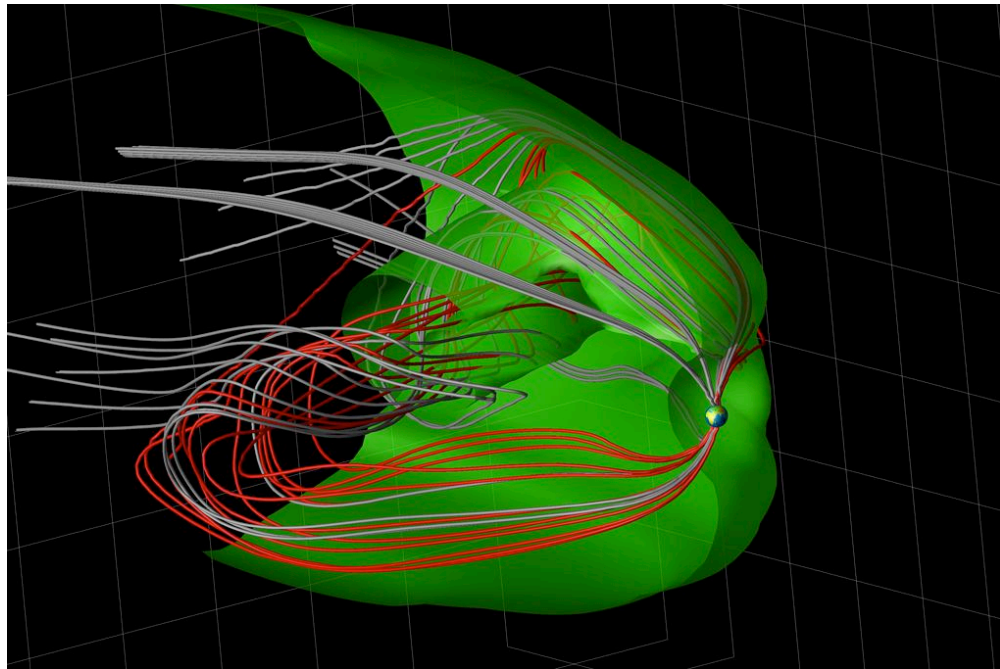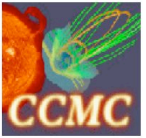Paula J. Reitan, Kristi A. Keller, Maria M. Kuznetsova Lutz Rastätter, and Michael Hesse

The Community Coordinated Modeling Center

NASA / Goddard Space Flight Center, Greenbelt, MD, USA

Science Data Processing Workshop 2002
    http://ccmc.gsfc.nasa.gov
    February 27-28, 2002

Magnetotail field topology in a three-dimensional global particle simulation

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[2] National Space Science and Technology Center, 320 Sparkman Drive, VP62 Huntsville, AL 35805, USA
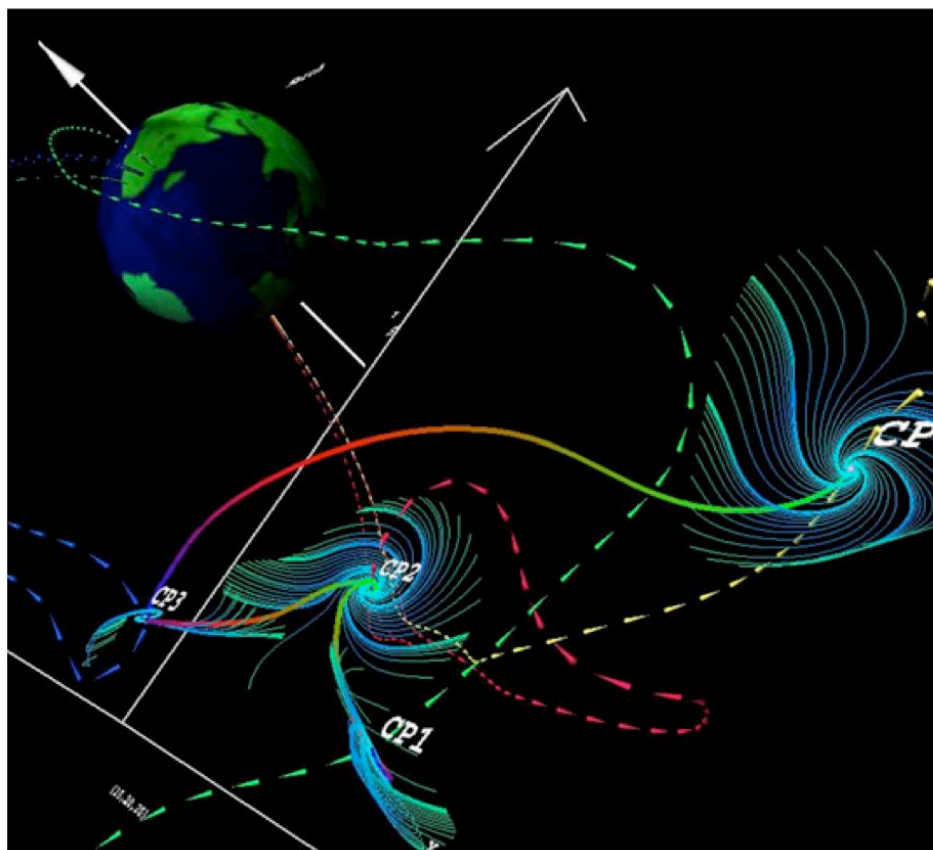[3] CETP/UVSQ/IPSL, 10–12 Avenue de l'Europe, FR-78140 Velizy, France

Figure 10. Magnetotail field topology or 3D x-point. Whole view seen from the magnetotail.